

DESCRIPTION

ELECTRIC POWER STEERING APPARATUS

5      Technical Field

The present invention relates to an electric power steering apparatus, and more particularly, to an electric power steering apparatus including a rack shaft and a pinion.

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Background Art

One known type of steering apparatus of a vehicle is a rack-and-pinion steering apparatus in which a rotational force and an amount of rotation (steering power) of a pinion are converted into a thrust in the axial direction and a stroke of a rack shaft by meshing engagement of the rack teeth of the rack shaft with the pinion. Here, in a relatively lightweight vehicle, a configuration in which a rack-and-pinion steering apparatus is incorporated in a so-called manual steering apparatus that outputs no assistive steering force is sometimes used. In such a case, travelling wheels must be driven only by the steering of a driver, and thus the setting is determined such that the amount of stroke per one rotation of a pinion (a stroke ratio) is made small in order to reduce the steering torque and to increase the

amount of steering at the same time. Furthermore, in a rack holding mechanism for holding a rack, the transmission efficiency has been improved, and the steering torque has been reduced by providing a rolling rack guide (as shown in Fig. 3, a type for pressing an arc surface 73a of a single roller 73 against the cylindrical back surface of a rack shaft 60 in order to ensure engagement between a pinion 53 and the rack shaft 60), etc., which supports the rack by a single roller, etc., rotating at a holding part for holding the back surface (the opposite side of the rack teeth) of the rack shaft.

On the other hand, in a relatively heavyweight vehicle, in general, it is necessary to provide a so-called power steering apparatus that outputs an assistive steering force in order to reduce steering power. Here, power steering apparatuses are roughly divided into hydraulic power steering apparatuses and electric power steering apparatuses. In a hydraulic power steering apparatus, a hydraulic pressure is generated by a control valve disposed on the pinion shaft in accordance with a steering torque applied to the steering wheel by a driver, and the hydraulic pressure is exerted on a hydraulic cylinder disposed on the rack shaft, thereby generating a thrust directly in the movement direction of the rack shaft. Accordingly, a steering torque applied on the steering wheel by the driver is sufficient by a small

torque needed to operate the control valve. Moreover, in order to reduce the amount of steering, the stroke ratio is set to be larger than that of a manual steering apparatus. Thus, the torque transmitted to the rack shaft through the rack-and-pinion apparatus is extremely small. Accordingly, even if the transmission efficiency deteriorates in some degree, the steering of the driver is not hindered. Therefore, in a rack holding mechanism for holding a rack, a sliding rack guide, which is more inexpensive than a rolling rack guide, is used (Japanese Unexamined Utility Model Application Publication Nos. 61-18976 and 61-124471).

In contrast, in an electric power steering apparatus, an assistive steering force is output to a steering shaft or a rack shaft by an electric motor in accordance with a steering torque applied to the steering wheel. The electric power steering apparatus has superior features in that it has a compact configuration, etc., when compared with a hydraulic power steering apparatus. For example, the steering apparatus does not need a hydraulic pump, hydraulic pipes, an operating oil tank, and so on. In the beginning, the electric power steering apparatus was adopted to a lightweight vehicle such as a compact car, etc. However, the electric power steering apparatus has been applied to a heavyweight vehicle in recent years. Here, electric power steering apparatuses include a so-called column-assist type

electric power steering apparatus in which an assistive steering force is directly output to the steering shaft by attaching an electric motor to the steering column, and a so-called pinion-assist type electric power steering  
5 apparatus in which an assistive steering force is directly output to the pinion shaft by attaching an electric motor to the rack-and-pinion apparatus. By an electric power steering apparatus of the latter type, a mighty force including an assistive steering force of an electric motor  
10 is transmitted between the pinion and the rack teeth of the rack shaft.

Moreover, in a relatively heavyweight vehicle, a much stronger force is steadily transmitted between the pinion  
15 and the rack teeth of the rack shaft in the case of a manual steering apparatus or a hydraulic power steering apparatus, and thus the bending stress and the surface pressure operated on the pinion and the rack teeth increase. In order to cope with this, it is possible to decrease the bending stress  
20 and the surface pressure by increasing the pressure angle or the torsion angle thereof. In particular, in a variable stroke-ratio-type rack-and-pinion steering apparatus in which the stroke ratio near the central part of the rack teeth has a large value and the stroke ratio at both ends  
25 has a small value, the pressure angle of the central part of the rack teeth which is used most frequently in normal

traveling tends to further increase.

Here, when a strong force is transmitted between the pinion and the rack teeth of the rack shaft, a separation force which separates the rack from the pinion also increases. Also, such a separation force further increases as the pressure angle increases. For example, in the case of a manual steering apparatus or a hydraulic power steering apparatus, in general, the pressure angle is about 20 degrees. In the case of an electric power steering apparatus, when a constant stroke-ratio-type rack-and-pinion steering apparatus is applied, the pressure angle is about 30 degrees, and when a variable stroke-ratio-type rack-and-pinion steering apparatus is applied, the pressure angle reaches about 45 degrees. By a simple calculation, in the case of the same rack thrust, an electric power steering apparatus to which a variable stroke-ratio-type rack-and-pinion steering apparatus is applied receives a separation force  $\tan 45^\circ / \tan 20^\circ = 2.75$  times that of a manual steering apparatus when compared. When compared with a hydraulic power steering apparatus, assuming that the amplification of the steering torque of a driver by hydraulic assisting is about 10 times, a separation force  $10 \times 2.75 = 27.5$  times as strong as the force is received.

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However, when such a separation force is received,

if a slide guide is used for supporting the back surface of the rack shaft, a frictional force is increased, and thus the transmission efficiency of the steering force is decreased. That is to say, in a manual steering apparatus or a hydraulic power steering apparatus, a slide guide is sufficient for supporting the rack shaft. However, in an electric power steering apparatus, a rack supporting mechanism having a smaller frictional force is required in place of the slide guide.

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Furthermore, in an electric power steering apparatus, there are problems caused by the torsion angle of the rack teeth of the rack shaft in addition to the problems caused by the increase of the separation force described above. That is to say, as the torsion angle increases, the rotational force which rotates the rack shaft about the axial thereof increases. This brings about defects such as abrasion of the pinion and the rack teeth by one-sided contact of the pinion and the rack teeth, an increase of the operating torque, etc. In particular, in the case of a so-called rack-assist type electric power steering apparatus in which an electric motor is disposed around the rack shaft in order to give a thrust to the rack shaft using a ball-screw mechanism, etc., including a ball screw and a nut, the rack shaft is further twisted by a reaction force of the nut, etc., and thus one-sided contact between the rack teeth and the pinion

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becomes more significant. However, there is a problem in that such twisting of the rack shaft cannot be supported appropriately by known rolling rack guides.

## 5 Disclosure of Invention

In view of the problems with such a known technique, an object of the present invention is to provide an electric power steering apparatus capable of restraining the twisting  
10 of the rack shaft and supporting the rack shaft with low friction.

In order to achieve the above object, according to the present invention, there is provided an electric power  
15 steering apparatus capable of outputting an assistive steering force by an electric motor, the electric power steering apparatus including:

a housing;

a rack shaft including rack teeth and being movably  
20 supported with respect to the housing; and

a pinion including pinion teeth meshing with the rack teeth, for transmitting a steering force from a steering wheel to the rack shaft; and

a supporting unit disposed in the housing, for  
25 supporting the rack shaft,

wherein an axis of the rack shaft and an axis of the

pinion intersect at an angle other than 90 degrees,

the rack shaft has guideway surfaces extending in the longitudinal direction for the supporting unit at least at two places on the periphery, and

5           the supporting unit includes a rolling member rolling while pressing each supporting unit guideway surface along the direction intersecting with each other when viewed in the longitudinal direction of the rack shaft, and when indicating each direction of the pressing forces from the  
10          rolling member to each supporting unit guideway surface by a line, respectively, the intersecting point of the lines is shifted from the center of the rack shaft.

          An electric power steering apparatus according to the  
15          present invention is an electric power steering apparatus capable of outputting an assistive steering force by an electric motor, the electric power steering apparatus including:

          a housing;  
20          a rack shaft including rack teeth and a screw part, and being movable with respect to the housing;

          a pinion including pinion teeth meshing with the rack teeth, for transmitting a steering force from a steering wheel to the rack shaft;

25          a supporting unit disposed in the housing, for supporting the rack shaft; and

a converting member for converting a rotational force of the electric motor into a thrust of the rack shaft using a nut screwed on the screw part,

5 wherein the rack shaft has guideway surfaces extending in the longitudinal direction for the supporting unit at least at two places on the periphery,

the supporting unit includes a rolling member rolling while pressing each supporting unit guideway surface along the direction intersecting with each other when viewed in  
10 the longitudinal direction of the rack shaft, and when indicating each direction of the pressing forces from the rolling member to each supporting unit guideway surface by a line, respectively, the intersecting point of the lines is shifted from the center of the rack shaft by urging the  
15 other end of the shaft member.

An electric power steering apparatus according to the present invention is an electric power steering apparatus capable of outputting an assistive steering force by an  
20 electric motor, the electric power steering apparatus including:

a housing;

a rack shaft including rack teeth, and being movable with respect to the housing;

25 a pinion including pinion teeth meshing with the rack teeth, for transmitting a steering force from a steering

wheel to the rack shaft; and

a supporting unit disposed in the housing, for supporting the rack shaft,

wherein the rack shaft has guideway surfaces extending  
5 in the longitudinal direction for the supporting unit at least at two places on the periphery,

the supporting unit includes a rolling member rolling while pressing each supporting unit guideway surface along the direction intersecting with each other when viewed in  
10 the longitudinal direction of the rack shaft, a shaft member having one end swingably held with respect to the housing and rotatably supporting the rolling member, and an urging means for pressing the rolling member toward the supporting unit guideway surface of the rack shaft by urging the other  
15 end of the shaft member.

An electric power steering apparatus according to the present invention is an electric power steering apparatus capable of outputting an assistive steering force by an  
20 electric motor, and the electric power steering apparatus includes: a housing; a rack shaft including rack teeth and movably supported with respect to the housing; and a pinion including pinion teeth meshing with the rack teeth, for transmitting a steering force from a steering wheel to the  
25 rack shaft; and a supporting unit disposed in the housing, for supporting the rack shaft, wherein an axis of the rack

shaft and an axis of the pinion intersect at an angle other than 90 degrees, the rack shaft has guideway surfaces extending in the longitudinal direction for the supporting unit at least at two places on the periphery, and the supporting unit includes a rolling member rolling while pressing each supporting unit guideway surface along the direction intersecting with each other when viewed in the longitudinal direction of the rack shaft, and when indicating each direction of the pressing forces from the rolling member to each supporting unit guideway surface by a line, respectively, the intersecting point of the lines is shifted from the center of the rack shaft. Thus, the rack shaft can be supported by the rolling member with low friction, and at the same time, the rack shaft can be supported from two different directions by pressing the supporting unit guideway surfaces provided on the outer circumferential surface of the rack shaft by the rolling members. Accordingly, since the axis of the rack shaft and the axis of the pinion intersect at an angle other than 90 degrees, the apparatus has a preferred configuration for supporting the rack shaft on which a rotational torque is developed in operation. Also, when indicating each direction of the pressing forces from the rolling member to each supporting unit guideway surface by a line, respectively, the intersecting point of the lines is shifted (offset) from the center of the rack shaft. Thus, it is possible to prevent the rotation of the rack shaft

and to maintain a smooth meshing engagement. Also, it is possible to press the rack teeth against the pinion teeth in a stable state by the resultant force of the pressing forces. In this regard, an axis of a rack shaft refers to  
5 a line (for example, an axis of the original raw material when a rack shaft is formed from a cylindrical raw material) passing through the center of the cross section perpendicular to the longitudinal direction of the rack shaft.

10 Incidentally, in one type of so-called rack-assist type electric power steering apparatus is that a rotational output of an electric motor is converted into a thrust in the longitudinal direction of the rack shaft using a ball screw and a nut. In this type of rack-assist type electric  
15 power steering apparatus, a rotational torque is originally developed about the axis of the rack shaft by a rotational reaction force of the nut.

In contrast, an electric power steering apparatus of  
20 the present invention is an electric power steering apparatus capable of outputting an assistive steering force by an electric motor, the electric power steering apparatus including: a housing; a rack shaft including rack teeth and a screw part, and being movable with respect to the housing;  
25 a pinion including pinion teeth meshing with the rack teeth, for transmitting a steering force from a steering wheel to

the rack shaft; a supporting unit disposed in the housing, for supporting the rack shaft; and a converting member for converting a rotational force of the electric motor into a thrust of the rack shaft using a nut screwed on the screw part, wherein the rack shaft has guideway surfaces extending in the longitudinal direction for the supporting unit at least at two places on the periphery, the supporting unit includes a rolling member rolling while pressing each supporting unit guideway surface along the direction intersecting with each other when viewed in the longitudinal direction of the rack shaft, and when indicating each direction of the pressing forces from the rolling member to each supporting unit guideway surface by a line, respectively, the intersecting point of the lines is shifted from the center of the rack shaft. Thus, since a rotational force of the electric motor is converted into a thrust of the rack shaft using the nut screwed on the screw part, it is possible to receive a rotational torque developed originally about the axis of the rack shaft in operation by the rolling members contacting the supporting unit guideway surfaces from different directions. Therefore, it is possible to support the rack shaft while ensuring smooth movement of the rack shaft in the axial direction. That is to say, a rotational torque about the axis of the rack shaft cannot be received without the shifted rolling members.

Incidentally, when a plurality of the rolling members are considered to be disposed as the first present invention described above, it becomes necessary to adjust a pressing force pressing the supporting unit guideway surface for each  
5 rolling member.

In contrast, an electric power steering apparatus of the present invention is an electric power steering apparatus capable of outputting an assistive steering force by an  
10 electric motor, the electric power steering apparatus including: a housing; a rack shaft including rack teeth, and being movable with respect to the housing; a pinion including pinion teeth meshing with the rack teeth, for transmitting a steering force from a steering wheel to the  
15 rack shaft; and a supporting unit disposed in the housing, for supporting the rack shaft, wherein the rack shaft has guideway surfaces extending in the longitudinal direction for the supporting unit at least at two places on the periphery, the supporting unit includes a rolling member rolling while  
20 pressing each supporting unit guideway surface along the direction intersecting with each other when viewed in the longitudinal direction of the rack shaft, a shaft member having one end swingably held with respect to the housing and rotatably supporting the rolling member, and an urging  
25 means for pressing the rolling member toward the supporting unit guideway surface of the rack shaft by urging the other end of the shaft member. Thus, it is possible to press the

rolling member against the supporting unit guideway surface while swinging the rolling member by the urging means urging only the other end with an appropriate pressing pressure. Accordingly, it becomes possible to ensure smooth operation  
5 by a simple configuration.

In particular, if the urging means includes a pressing part for contacting the other end of each shaft member and an elastic member for elastically urging the pressing part,  
10 it is possible, for example, to perform the urging of each axis member using the single pressing part. Furthermore, since an elastic force by the elastic member is used, it is possible to provide a stable urging force even if friction, etc., arises between the rolling member and the supporting  
15 unit guideway surface.

Furthermore, when indicating each direction of the pressing forces from the rolling member to each supporting unit guideway surface by a line, respectively, the  
20 intersecting point of the lines is preferably shifted from the center of the rack shaft.

Also, the rack shaft preferably has a position-regulating part for regulating a position of the  
25 rolling member.

Furthermore, a conical surface facing outward is preferably formed at least at one end face of the rolling member.

5           Also, at least a portion for supporting the rolling member, of the supporting unit, is preferably formed by a molding process.

#### Brief Description of the Drawings

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Figs. 1A and 1B are sectional views of a rack-and-pinion steering apparatus according to a first embodiment.

15           Fig. 2 is a sectional view of a rack-and-pinion steering apparatus according to a second embodiment.

Fig. 3 is a sectional view of a rack-and-pinion steering apparatus according to a known technique.

20           Fig. 4 is a partially omitted sectional view of a rack-assist type electric power steering apparatus according to a third embodiment.

25           Fig. 5 is a sectional view showing the configuration in Fig. 4, cut off by an input shaft 202 in an axial direction.

Fig. 6 is a sectional view, similar to Fig. 5, of an electric power steering apparatus according to a fourth embodiment.

5            Fig. 7 is a sectional view, similar to Fig. 5, of an electric power steering apparatus according to a fifth embodiment.

10           Fig. 8 is a sectional view, similar to Fig. 5, of an electric power steering apparatus according to a sixth embodiment.

15           Figs. 9A to 9D are views illustrating an electric power steering apparatus according to a seventh embodiment.

            Figs. 10A to 10D are views illustrating an electric power steering apparatus according to an eighth embodiment.

20           Fig. 11 is a view, similar to Fig. 9A, of an electrically driven power rack-and-pinion steering apparatus according to a ninth embodiment, applied to a rack-assist type electric power steering apparatus.

25           Fig. 12 is a sectional view, similar to Figs. 1A and 1B, in the ninth embodiment.

Fig. 13 is a sectional view, similar to Fig. 2, of an electric power steering apparatus according to a tenth embodiment.

5            Fig. 14 is a sectional view, similar to Fig. 2, of an electric power steering apparatus according to an eleventh embodiment.

10           Fig. 15 is a sectional view, similar to Fig. 2, of an electric power steering apparatus according to a twelfth embodiment.

15           Fig. 16 is a sectional view, similar to Fig. 2, of an electric power steering apparatus according to a thirteenth embodiment.

            Figs. 17A to 17D are views illustrating assembly steps of the main unit according to the embodiments in Figs. 1A, 1B, and 2.

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            Fig. 18 is a view of the configuration in Fig. 17A as viewed in the direction of the arrow XVIII.

25           Figs. 19A and 19C are views illustrating assembly steps of the main unit according to the embodiments in Figs. 15 and 16.

Fig. 20 is a view of the configuration in Fig. 19A as viewed in the direction of the arrow XX.

5            Fig. 21 is a view of the configuration in Fig. 19A as viewed in the direction of the arrow XXI.

Fig. 22 is a view of the configuration in Fig. 19A as viewed in the direction of the arrow XXII.

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Fig. 23 is a view showing the main unit in Fig. 22, cut off by the line XXIII-XXIII as viewed in the arrow direction.

15    Best Mode for Carrying out the Invention

In the following, a description will be given of embodiments of the present invention based on the drawings.

20           Figs. 1A and 1B are sectional views of a rack-and-pinion steering apparatus according to a first embodiment. Fig. 1A illustrates a state in which a supporting unit is assembled. Fig. 1B illustrates a state in which the supporting unit is decomposed. For easy understanding, the sectional view of each part is assembled (in the following, this is the same for similar sectional views).

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In Figs. 1A and 1B, an output shaft (pinion) 3 extending in a housing 1 is connected to an unillustrated steering shaft, and rotatably supported by bearings 5, 6 with respect to the housing 1. The inner ring of the bearing 6 is fixed to the end of the output shaft 3 by a nut 7, and the outer ring of the bearing 6 is attached to the housing 1 by screwing a fixing member 8.

The housing 1 is provided with a hollow columnar portion 1c formed from the circumference of the rack shaft 10 extending leftward in the figure. A supporting unit 20 is disposed in the hollow columnar portion 1c. The supporting unit 20 includes a substantially cylindrical main unit 21, two shafts 22 attached in bores of the main unit 21, cylindrical rollers 23, which are rotating members, attached to individual shafts 22, a screw member 24 for attaching the main unit 21 to the hollow columnar portion 1c, a disc spring 25 disposed between the screw member 24 and the main unit 21 for urging the main unit 21 to the rack shaft 10, and a lock member 26 of the screw member 24. By adjusting an amount of screwing of the screw member 24, the amount of compression of the disc spring 25 is changed, thereby making it possible to adjust the pressing force to the rack shaft 10. After the adjustment, the screw member 24 can be locked by the lock member 26 to prevent the screw member 24 from being loosened. The surface (called the back surface) of the rack shaft 10 which is opposite

to rack teeth 10a has a shape cut away at a left upper part and a left lower part in Figs. 1A and 1B in a sectional view thereof. Here, two rolling contact surfaces (that is to say, supporting unit guideway surfaces extending in the longitudinal direction) 10b, 10b extending in the longitudinal direction, are formed respectively, and a projection 10c is formed therebetween. The rolling contact surfaces 10b, 10b are symmetrically disposed with respect to the center of the rack shaft 10 in cross section. The axis of the rack shaft 10 and the axis of the pinion 3 intersect at an angle other than 90 degrees. In this regard, the rack teeth 10a of the rack shaft 10 are formed from a round bar as a raw material by performing machine work or cold molding. In the case of a rack-assist type electric power steering apparatus, a threaded groove is formed in the periphery of a round bar as a raw material (not shown). Accordingly, the center of the rack shaft 10 refers to the center of the round bar or the center of the threaded groove.

Two shafts 22 are disposed parallel to the rolling contact surfaces 10b and perpendicularly with respect to the rack shaft line, and support the cylindrical rollers 23 rotatably through bearings 22a. A position K at which bisectors L (matches the direction of a pressing force of the cylindrical rollers 23 against the rolling contact surfaces 10b) dividing the two cylindrical rollers 23 in

two in an axial direction intersect with each other is disposed so as to be offset by  $\Delta$  from a center O of the rack shaft 10 to the rack teeth 10a side. The bisectors L are perpendicular to each other here. Crowning processing is preferably added to both ends of the cylindrical rollers 23 in order to alleviate edge load on the rolling contact surfaces 10b, 10b. The two cylindrical rollers 23 constitute pressing means for pressing the rack shaft 10 toward the output shaft 3 from two directions.

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To describe the operation of the present embodiment, when a steering force is input into an unillustrated steering wheel, this steering force is transmitted to the output shaft 3 through an unillustrated steering shaft. The rotational force of the output shaft 3 is converted into a thrust of the rack shaft 10 in the longitudinal direction through the pinion teeth 3a and the rack teeth 10a having a meshing engagement with each other. The rack shaft 10 is moved in the direction perpendicular to the page surface by this thrust in the longitudinal direction. Thereby, unillustrated wheels are steered. At this time, the cylindrical rollers 23 roll on the rolling contact surfaces 10b, and allow the rack shaft 10 to move with a small friction.

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Here, when a strong force is transmitted between the output shaft 3 and the rack shaft 10, a separation force

which separates the rack shaft 10 from the output shaft 3  
arises. In the present embodiment, this separation force  
can be supported by a pair of the cylindrical rollers 23  
disposed at symmetrical positions with respect to the center  
5 of the rack shaft 10. At the same time, when a strong force  
is transmitted between the output shaft 3 and the rack shaft  
10, a rotational force which causes the rack shaft 10 to  
rotate about the center thereof. Such a rotational force  
becomes strong in particular when the axis of the rack shaft  
10 intersects the axis of the pinion 3 at an angle other  
10 than 90 degrees. In the present embodiment, this rotational  
force can be supported by pair of the cylindrical rollers  
23 disposed at symmetrical positions with respect to the  
center of the rack shaft 10. In this regard, since the  
15 bisectors L of the two cylindrical rollers 23 intersect at  
right angles with each other, a pressing force on one of  
the rolling contact surfaces 10b advantageously does not  
affect the pressing force between the other of the rolling  
contact surfaces 10b and the cylindrical roller 23.

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Further, in the present embodiment, since the position  
K at which bisectors L of the two cylindrical rollers 23  
intersect with each other is disposed so as to be offset  
by  $\Delta$  from the center O of the rack shaft 10 to the rack teeth  
25 10a side, the resultant force of these forces presses the  
rack shaft 10 in the direction toward the output shaft 3,

it becomes possible to have a stable engagement between the rack shaft 10 and the output shaft 3.

5 In the present embodiment, the main unit 21 can be detached from the left end of the hollow columnar portion 1c integrally with the cylindrical rollers 23 as shown in Fig. 1B by loosening the lock member 26 and the screw member 24 and detaching them with the disc spring 25, it is easy to assemble the unit and disassemble the unit at maintenance  
10 time.

Fig. 2 is a sectional view of a rack-and-pinion steering apparatus according to a second embodiment in which the present invention is applied to a rack-assist type electric  
15 power steering apparatus. Referring to Fig. 2, a housing 101 includes a main unit 101a and a cover member 101b which are fixed using an unillustrated bolt. An input shaft 102 and an output shaft 103 extend in the housing 101. The input shaft 102 is hollow, and the upper end of the input shaft  
20 102, shown in the figure, is connected to an unillustrated steering shaft. Further, the steering shaft is connected to an unillustrated steering wheel. The input shaft 102 is rotatably supported with respect to the housing 101 by a bearing 104. A torsion bar 105 whose upper end shown in the  
25 figure is pin coupled to the input shaft 102 and whose lower end is serration coupled to the output shaft 103 extends

in the input shaft 102.

A torque sensor 106 which detects a steering torque based on the torsion of the torsion bar 105 in proportion to the received torque is provided (only a part is shown) in the lower surroundings of the input shaft 102 shown in the figure. The torque sensor 106 detects a relative angular displacement between the input shaft 102 and the output shaft 103 based on the torsion of the torsion bar 105 in a mechanical manner (may be electro-magnetically), and outputs it as an electric signal to an unillustrated control circuit.

The output shaft 103 is rotatably supported with respect to the housing 101 by the bearings 115 and 116, and is provided with pinion teeth 103a formed in the central part thereof. The pinion teeth 103a has a meshing engagement with the rack teeth 110a of the rack shaft 110 extending in the perpendicular direction to the page surface. Both ends of the rack shaft 110 are connected to an unillustrated wheel steering mechanism.

The housing 101 is provided with a hollow columnar portion 101c formed from the circumference of the rack shaft 110 extending leftward in the figure. A supporting unit 120 is disposed in the hollow columnar portion 101c. The supporting unit 120 includes a substantially cylindrical

main unit 121, two shafts 122 attached in bores of the main unit 121, cylindrical rollers 123, which are rotating members, attached to individual shafts 122, a screw member 124 for attaching the main unit 121 to the hollow columnar portion 101c, a disc spring 125 disposed between the screw member 124 and the main unit 121 for urging the main unit 121 to the rack shaft 110, and a lock member 126 of the screw member 124. By adjusting an amount of screwing of the screw member 124, the amount of compression of the disc spring 125 is changed, thereby making it possible to adjust the pressing force to the rack shaft 110. After the adjustment, the screw member 124 can be locked by the lock member 126 to prevent the screw member 124 from being loosened. The surface (called the back surface) of the rack shaft 110 which is opposite to rack teeth 110a has a shape cut away at a left upper part and a left lower part in Fig. 2 in a sectional view thereof. Here, two rolling contact surfaces (that is to say, supporting unit guideway surfaces extending in the longitudinal direction) 110b, 110b extending in the longitudinal direction are formed, respectively, and a projection 110c is formed therebetween. The rolling contact surfaces 110b, 110b are symmetrically disposed with respect to the center of the rack shaft 110 in cross section. The axis of the rack shaft 110 and the axis of the pinion 103 intersect at an angle other than 90 degrees.

Two shafts 122 are disposed parallel to the rolling contact surfaces 110b and perpendicularly to the rack shaft line, and support the cylindrical rollers 123 rotatably through bearings 122a. A position at which bisectors (not shown) of the two cylindrical rollers 123 intersect at right angles is offset in the same manner as the first embodiment. Crowning processing is preferably added to both ends of the cylindrical rollers 123 in order to alleviate edge load on the rolling contact surfaces 110b. The two cylindrical rollers 123 constitute pressing means for pressing the rack shaft 110 toward the output shaft 103 from two directions.

A description will be given of the operation of the present embodiment. When a steering force is input into an unillustrated steering wheel, the torque sensor 106 detects a steering torque from an amount of torsion of the torsion bar 105. An assistive steering force is output from an unillustrated electric motor in accordance with it. Here, when the steering force is transmitted to the output shaft 103, the rotational force of the output shaft 103 is converted into a thrust of the rack shaft 110 in the longitudinal direction through the pinion teeth 103a and the rack teeth 110a having a meshing engagement with each other. The rack shaft 110 is moved in the direction perpendicular to the page surface by this thrust in the longitudinal direction. Thereby, unillustrated wheels are steered. At this time,

cylindrical rollers 123 roll on the rolling contact surfaces 110b, and allow the rack shaft 110 to move with a small friction.

5           In the same manner as the above-described embodiment, when a strong force is transmitted between the output shaft 103 and the rack shaft 110, a separation force which separates the rack shaft 110 from the output shaft 103 arises. In the present embodiment, this separation force can be supported  
10 by a pair of the cylindrical rollers 123 disposed at symmetrical positions with respect to the center of the rack shaft 110. At the same time, when a strong force is transmitted between the output shaft 103 and the rack shaft 110, a rotational force which causes the rack shaft 110 to  
15 rotate about the center thereof. Such a rotational force becomes strong in particular when the axis of the rack shaft 110 intersects the axis of the pinion 103 at an angle other than 90 degrees. In the present embodiment, this rotational force can be supported by pair of the cylindrical rollers  
20 123 disposed at symmetrical positions with respect to the center of the rack shaft 110. In this regard, since the bisectors L of the two cylindrical rollers 123 intersect at right angles with each other, a pressing force on one of the rolling contact surfaces 110b advantageously does  
25 not affect the pressing force between the other of the rolling contact surfaces 110b and the cylindrical roller 123.

Further, in the present embodiment, since the position at which bisectors of the two cylindrical rollers 123 intersect with each other is also disposed so as to be offset from the center of the rack shaft 110 to the rack teeth 110a side, it becomes possible to prevent the rotation of the rack shaft and to maintain a smooth meshing state. Also, since the resultant force of these forces presses the rack shaft 110 in the direction toward the output shaft 103, it becomes possible to have a stable engagement between the rack shaft 110 and the output shaft 103.

Incidentally, in the embodiments described above, the adjustments of the pressing force of the cylindrical rollers 23, 123 and the rolling contact surfaces 10b, 110b can be made by screwing up or screwing off the screw member 24, 124 against the housing 1, 101 to change an amount of the elastic deformation of the disc spring 25, 125. The main unit 21, 121 presses the shafts 22, 122 by the elastic force based on the amount of the elastic deformation of the disc spring 25, 125. Thereby, the cylindrical rollers 23, 123 are pressed against the rolling contact surfaces 10b, 110b.

Fig. 4 is a partially omitted sectional view of a rack-assist type electric power steering apparatus according to a third embodiment. In Fig. 4, a cover member 201C is attached to the right end of a rack housing 201A formed

integrally with the housing 201 by a bolt 201D through a distance member 201B. The rack housing 201A is fixed to an unillustrated vehicle body. A rack shaft 210 is inserted into the rack housing 201A. The rack shaft 210 is connected to tie rods 208, 209 at both ends thereof. The tie rods 208, 209 are connected to an unillustrated wheel-steering mechanism.

In the vicinity of the right end of the rack shaft 210 in Fig. 4, a spiral external threaded groove 210d is formed on the periphery thereof. A cylindrical ball screw nut 230 is disposed on the circumference thereof, is rotatably supported by a bearing 232 with respect to the distance member 201B, and is rotatably supported by bearings 233, 234 with respect to the cover member 201C. A spiral internal threaded groove 230a is formed on the internal circumference of the ball screw nut 230. The external threaded groove 210d and the internal threaded groove 230a constitute a rolling movement path. A large number of balls 231 (only a part is shown) are accommodated in this rolling movement path.

The balls 231 have a function of reducing a frictional force which occurs when the ball screw nut 230 and the rack shaft 210 are rotated relatively. In this regard, the ball screw nut 231 has an unillustrated circulating path. When the ball screw nut 230 is rotated, the balls 231 are capable

of circulating through this circulating path.

A rotational torque output from the electric motor 235 is transmitted to the ball screw nut 230 by a so-called traction-drive method through rollers 236 having rolling contact with the periphery of the ball screw nut 230 and the periphery of a rotational shaft 235a of the electric motor 235 attached to the rack housing 201A, respectively. In this regard, the rotational torque may be transmitted by a gear-transmission method in place of the traction-drive method. The ball screw nut 230 constitutes a nut, and the ball screw nut 230 and the rack shaft 210 including the external thread 210d constitute a conversion member.

Fig. 5 is a sectional view showing the configuration in Fig. 4, cut off by an input shaft 202 in an axial direction. In Fig. 5, the input shaft 202 and an output shaft 203 extend in the housing 201. The input shaft 202 is hollow, and the upper end of the input shaft 202, shown in the figure, is connected to an unillustrated steering shaft. Further, the steering shaft is connected to an unillustrated steering wheel. The input shaft 202 is rotatably supported with respect to the housing by a bearing 204. A torsion bar 205 whose upper end shown in the figure is pin coupled to the input shaft 202 and whose lower end is serration coupled to the output shaft 203 extends in the input shaft 202.

A torque sensor 206 which detects a steering torque based on the torsion of the torsion bar 205 in proportion to the received torque is provided (only a part is shown) in the lower surroundings of the input shaft 202 shown in the figure. This torque sensor 206 is the same as the torque sensor of the embodiment described above, and thus the detailed description will be omitted.

The output shaft 203 is rotatably supported with respect to the housing 201 by the bearings 215 and 216, and is provided with pinion teeth 203a formed in the central part thereof. The pinion teeth 203a has a meshing engagement with the rack teeth 210a of the rack shaft 210 extending in the perpendicular direction to the page surface. Both ends of the rack shaft 110 are connected to an unillustrated wheel steering mechanism through tie rods 208, 209 as shown in Fig. 4.

The housing 201 is provided with a hollow columnar portion 201c formed from the circumference of the rack shaft 210 extending in the lower left direction in the figure and a hollow columnar portion 201e formed extending in the upper left direction in the lower portion in the figure. Supporting units 220, 220 having the same configuration are disposed in the hollow columnar portions 201c, 201e. Each supporting

unit 220 includes a substantially cylindrical main unit 221,  
a shaft 222 attached in a bore of the main unit 221, a  
cylindrical roller 223, which is a rotating member, attached  
to the shaft 222, a screw member 224 for attaching the main  
5 unit 221 to the hollow columnar portion 201c or 201e, a disc  
spring 225 disposed between the screw member 224 and the  
main unit 221 for urging the main unit 221 to the rack shaft  
210, and a lock member 226 of the screw member 224. By  
adjusting an amount of screwing of the screw member 224,  
10 the amount of compression of the disc spring 225 is changed,  
thereby making it possible to adjust the pressing forces  
F1 and F2 (the rack shaft 210 is displaced upward or downward  
in the figure such that an upward component and a downward  
component of these forces are balanced, and thus the pressing  
15 force F1 and the pressing force F2 become equal with each  
other) to the rack shaft 210. After the adjustment, the screw  
member 224 can be locked by the lock member 226 to prevent  
the screw member 224 from being loosened.

20           The surface (the back surface) of the rack shaft 210  
which is opposite to rack teeth 210a has a shape cut away  
at a left upper part and a left lower part in Fig. 4 in a  
sectional view thereof. Here, two rolling contact surfaces  
(that is to say, supporting unit guideway surfaces extending  
25 in the longitudinal direction) 210b, 210b extending in the  
longitudinal direction are formed, respectively, and a

projection 210c is formed therebetween. The rolling contact surfaces 210b, 210b are symmetrically disposed with respect to the bisector (a horizontal line in the figure) of the rack shaft 210 in cross section. The axis of the rack shaft  
5 210 and the axis of the pinion 203 intersect at an angle other than 90 degrees.

A shaft 222 of each supporting unit 220 is disposed perpendicularly to the rack shaft line and parallel to the  
10 opposed rolling contact surface 210b, and supports the cylindrical roller 223 rotatably through bearings 222a. A position at which bisectors (have the same directions as the pressing forces F1 and F2) of the two cylindrical rollers 223 intersect at right angles is offset in the same manner  
15 as the embodiments described above. Crowning processing is preferably added to both ends of the cylindrical rollers 223 in order to alleviate edge load on the rolling contact surfaces 210b. The two cylindrical rollers 223 constitute pressing means for pressing the rack shaft 210 toward the  
20 output shaft 203 from two directions.

According to the present embodiment, the adjustments of the pressing forces F1 and F2 of the two cylindrical rollers 223 against the rolling contact surfaces 210b can be made  
25 by screwing up or screwing off the screw members 224 against the housing 201 to change amounts of the elastic deformation

of the disc springs 225. In such a case, since the directions of the elastic forces of the disc springs 225 match the directions of the pressing forces F1 and F2. Accordingly, those elastic forces can be all (excluding a frictional loss) used as the pressing forces F1 and F2. Thus, the configuration of the supporting unit 220 is made smaller and the weight reduction can be realized. Also, since the rack shaft 210 is supported from three directions, sufficient supporting rigidity is ensured. Thus, it becomes possible to omit a member such as a bush which is usually used in a known technique, thereby more effective use of space can be achieved.

Fig. 6 is a sectional view, similar to Fig. 5, of an electric power steering apparatus according to a fourth embodiment. The present embodiment is slightly different from the embodiment shown in Fig. 5 merely in the configuration of the supporting unit. Thus, common components other than that are marked with the same numerals and symbols, and those descriptions are omitted.

In the present embodiment, the lower supporting unit 220 in Fig. 6 is the same as that of the embodiment in Fig. 5. However, a disc spring is omitted in the upper supporting unit 220'. Accordingly, the present embodiment is different only in that the screw member 224 presses directly on the

main unit 221. According to the present embodiment, the adjustments of the pressing forces  $F_1$  and  $F_2$  of the two cylindrical rollers 223 against the rolling contact surfaces 210b can be made by screwing up or screwing off the screw members 224 against the housing 201 in the same manner as the embodiment in Fig. 5. When a wear-out is caused by, for example vibration, etc., at a contacting portion between the screw member 224 of the upper supporting unit 220' and the main unit 221, the rack shaft 210 is pushed upward in the figure by the urging force of the disc spring 225 of the lower supporting unit 220. Thereby, the surface pressure between the screw member 224 of the upper supporting unit 220' and the main unit 221 is substantially maintained. Thus, the pressing forces  $F_1$  and  $F_2$  do not grow unbalanced, and the rack shaft 210 can be supported stably for a long period of time.

Fig. 7 is a sectional view, similar to Fig. 5, of an electric power steering apparatus according to a fifth embodiment. The present embodiment is also different from the embodiment shown in Fig. 5 merely in the configuration of the supporting unit. Thus, common components other than that are marked with the same numerals and symbols, and those descriptions are omitted.

25

In the present embodiment, the lower supporting unit

220 in Fig. 7 is the same as that of the embodiment in Fig. 5. However, a mechanism of adjusting the pressing force independently is omitted in the upper supporting unit 320. More specifically, the supporting unit 320 includes a  
5 substantially cylindrical main unit 321 fixed in the hollow columnar portion 201e by a snap ring 326, a shaft 222 attached in a bore of the main unit 321, and a cylindrical roller 223, which is a rotating member, rotatably supported by the bearing 222a about the shaft 222. In this regard, the main  
10 unit 321 and the hollow columnar portion 201e are sealed by an O-ring 327.

In the present embodiment, it is possible to adjust the pressing forces F1 and F2 of the two cylindrical rollers  
15 223 against the rolling contact surfaces 210b by screwing up or off the screw member 224 of the lower supporting unit 220 against the housing 201 to change an amount of compression of the disc spring 225. In this case, the rack shaft 210 is displaced upward or downward in the figure, and thus the  
20 pressing forces F1 and F2 become equal.

Fig. 8 is a sectional view, similar to Fig. 5, of an electric power steering apparatus according to a sixth embodiment. The present embodiment is also different from  
25 the embodiment shown in Fig. 5 merely in the configuration of the supporting unit. Thus, common components other than

that are marked with the same numerals and symbols, and those descriptions are omitted.

5        In the present embodiment, the lower supporting unit 220 in Fig. 8 is the same as that of the embodiment in Fig. 5. However, an upper supporting unit 420 has a configuration in which the cylindrical roller 223 is fixed. More specifically, the supporting unit 420 includes a shaft 222 inserted in a bore 201f formed in the hollow columnar portion 201e and a cylindrical roller 223, which is a rotating member, 10        rotatably supported by the bearing 222a about the shaft 222. In this regard, the external end of the hollow columnar portion 201e is sealed by a cover member 426.

15        In the present embodiment, it is also possible to adjust the pressing forces  $F_1$  and  $F_2$  of the cylindrical rollers 223 against the rolling contact surfaces 210b by screwing up or off the screw member 224 of the lower supporting unit 220 against the housing 201 to change an amount of compression 20        of the disc spring 225. In this case, the rack shaft 210 is displaced upward or downward in the figure, and thus the pressing forces  $F_1$  and  $F_2$  become equal. Also, when a wear-out is caused by, for example vibration, etc., at each part, the rack shaft 210 is pushed upward by the urging force of 25        the disc spring 225 of the lower supporting unit 220. Thus, the pressing forces  $F_1$  and  $F_2$  do not grow unbalanced, and

the rack shaft 210 can be supported stably for a long period of time.

Incidentally, in order to cause the cylindrical roller  
5 223 to roll smoothly, it is necessary for the rotational  
shafts of the cylindrical rollers 223 to be at right angles  
to the rolling direction with good precision. Here, since  
the hollow columnar portion 201c, 201e and the main unit  
221, 321 fitting that portion are both cylindrical, in order  
10 to position the rotational shaft of the cylindrical roller  
223, it is necessary to prevent the rotation of the main  
unit 221. On the other hand, in order to achieve the  
prevention of the rotation, a non-circular inner hole is  
considered to be formed in the hollow columnar portion 201c,  
15 201e accommodating the cylindrical roller 223. However,  
that requires a lot of work and incurs an increase in cost.  
Thus, in the following embodiments, the prevention of the  
rotation of the main unit 221 (although the description will  
be omitted, the main unit 321 is also possible in the same  
20 manner) is achieved as described below.

Fig. 9A is a partially sectional view of an electric  
power steering apparatus according to a seventh embodiment  
as viewed from the same direction as that of Fig. 4. Fig.  
25 9B is a view showing the configuration in Fig. 9A, cut off  
by the line IXB-IXB as viewed in the arrow direction. Fig.

9C is a view showing the configuration in Fig. 9B, cut off by the line IXC-IXC as viewed in the arrow direction. Fig. 9D is a view showing the configuration in Fig. 9B, cut off by the line IXD-IXD as viewed in the arrow direction. The embodiment shown in Figs. 9A to 9D is obtained by applying the invention to the embodiment shown in Fig. 7, and thus a description will be given of the present embodiment with reference to Fig. 7 and Figs. 9A to 9D.

10           In the seventh embodiment, two cylindrical rollers 223 have caster angles. More specifically, the axis of the main unit 321 supporting the cylindrical roller 223 of the upper supporting unit 320 in Fig. 9A is inclined at a angle of  $\theta$  with respect to the direction perpendicular to the rolling contact surface 210b of the rack shaft 210 to the right side as viewed in Fig. 9A as shown in Fig. 9C. Accordingly, the pressing force against the cylindrical roller 223 exerted by the main unit 321 passes the middle of the center P1 of the cylindrical roller, and intersects the rolling contact surface 210b at a position different from the middle of the contact point P2 between the cylindrical roller 223 and the rolling contact surface 210b. When the cylindrical roller 223 rolls on the rolling contact surface 210b, it is possible to autonomously adjust the position of the cylindrical roller 223 such that the axis of the cylindrical roller 223 is perpendicular to the rolling direction using this difference.

Thus, it is possible to achieve the prevention of the rotation of the main unit 321 without providing complicated work and additional parts.

5           In the same manner, the axis of the main unit 221 supporting the cylindrical roller 223 of the lower supporting unit 220 in Fig. 9A is inclined at a angle of  $\theta$  with respect to the direction perpendicular to the rolling contact surface 210b of the rack shaft 210 to the left side as viewed in  
10   Fig. 9A as shown in Fig. 9D. Accordingly, the pressing force against the cylindrical roller 223 exerted by the main unit 221 passes the middle of the center P3 of the cylindrical roller, and intersects the rolling contact surface 210b at a position different from the middle of the contact point  
15   P4 between the cylindrical roller 223 and the rolling contact surface 210b. When the cylindrical roller 223 rolls on the rolling contact surface 210b, it is possible to autonomously adjust the position of the cylindrical roller 223 such that the axis of the cylindrical roller 223 is perpendicular to  
20   the rolling direction using this difference. Thus, it is possible to achieve the prevention of the rotation of the main unit 221 without providing complicated work and additional parts. In this regard, in the present embodiment, each part is disposed such that the central point P5 (Fig.  
25   9A) of a meshing engagement between the pinion teeth 203a (Fig. 7) and the rack teeth 210a, and points P1 to P4 are

coplanar.

Fig. 10A is a partially sectional view of an electric power steering apparatus according to an eighth embodiment as viewed from the same direction as that of Fig. 4. Fig. 10B is a view showing the configuration in Fig. 10A, cut off by the line XB-XB as viewed in the arrow direction. Fig. 10C is a view showing the configuration in Fig. 10B, cut off by the line XC-XC as viewed in the arrow direction. Fig. 10D is a view showing the configuration in Fig. 10B, cut off by the line XD-XD as viewed in the arrow direction. The embodiment shown in Figs. 10A to 10D is also obtained by applying the invention to the embodiment shown in Fig. 7, and thus a description will be given of the present embodiment with reference to Fig. 7 and Figs. 10A to 10D.

In the eighth embodiment, two cylindrical rollers 223 have caster angles. More specifically, the axis of the main unit 321 supporting the cylindrical roller 223 of the upper supporting unit 320 in Fig. 10A is inclined at a angle of  $\theta$  with respect to the direction perpendicular to the rolling contact surface 210b of the rack shaft 210 to the right side as viewed in Fig. 10A as shown in Fig. 10C. Accordingly, the pressing force against the cylindrical roller 223 exerted by the main unit 321 passes the middle of the center P1 of the cylindrical roller, and intersects the rolling contact

surface 210b at a position different from the middle of the contact point P2 between the cylindrical roller 223 and the rolling contact surface 210b. When the cylindrical roller 223 rolls on the rolling contact surface 210b, it is possible to autonomously adjust the position of the cylindrical roller 223 such that the axis of the cylindrical roller 223 is perpendicular to the rolling direction using this difference. Thus, it is possible to achieve the prevention of the rotation of the main unit 321 without providing complicated work and additional parts.

In the same manner, the axis of the main unit 221 supporting the cylindrical roller 223 of the lower supporting unit 220 in Fig. 10A is inclined at an angle of  $\theta$  with respect to the direction perpendicular to the rolling contact surface 210b of the rack shaft 210 to the left side as viewed in Fig. 10A as shown in Fig. 10D. Accordingly, the pressing force against the cylindrical roller 223 exerted by the main unit 221 passes the middle of the center P3 of the cylindrical roller, and intersects the rolling contact surface 210b at a position different from the middle of the contact point P4 between the cylindrical roller 223 and the rolling contact surface 210b. When the cylindrical roller 223 rolls on the rolling contact surface 210b, it is possible to autonomously adjust the position of the cylindrical roller 223 such that the axis of the cylindrical roller 223 is perpendicular to

the rolling direction using this difference. Thus, it is possible to achieve the prevention of the rotation of the main unit 221 without providing complicated work and additional parts. In this regard, in the present embodiment, each part is disposed such that the point P1, P1 and the point P3, P4 are different by a distance  $\Delta$  in the opposite directions to each other with respect to the central point P5 (Fig. 10A) of a meshing engagement between the pinion teeth 203a (Fig. 7) and the rack teeth 210a.

10

Fig. 11 is a view, similar to Fig. 9A, of an electrically driven power rack-and-pinion steering apparatus according to a ninth embodiment, applied to a rack-assist type electric power steering apparatus. Fig. 12 is a sectional view, similar to Figs. 1A and 1B, in this embodiment. In Fig. 11, an output shaft 503, which is shown only partially, extends vertically in a housing 501, and is rotatably supported by a bearing 516.

15

The output shaft 503 is provided with pinion teeth 503a formed in the central part thereof. The pinion teeth 503a has a meshing engagement with the rack teeth 510a of the rack shaft 510 extending in the perpendicular direction to the page surface. Both ends of the rack shaft 510 are connected to an unillustrated wheel steering mechanism.

20

25

The housing 501 is provided with a hollow columnar portion 501c formed from the circumference of the rack shaft 510 extending leftward in Fig. 12. A supporting unit 520 is disposed in the hollow columnar portion 501c. The  
5 supporting unit 520 includes a substantially cylindrical main unit 521, swingable shafts 522 which are two shaft members swingably supported at one end thereof by a pin 528 with respect to the housing 501, cylindrical rollers 523, which are rotating members, rotatably supported by bearings 522a  
10 about each of the swingable shafts 522, a screw member 524 for attaching the main unit 521 to the hollow columnar portion 501c, a disc spring 525 disposed between the screw member 524 and the main unit 521 for urging the main unit 521 to the rack shaft 510 as an elastic member, and a lock member  
15 526 for the screw member 524.

The two swingable shafts 522 are preferably disposed parallel to rolling contact surfaces 510b in an assembled state. At this time, a position at which bisectors (not  
20 shown) of the two cylindrical rollers 523 intersect at right angles is offset in the same manner as the first embodiment. Crowning processing is preferably added to both ends of the cylindrical rollers 523 in order to alleviate edge load on the rolling contact surfaces 510b. The two cylindrical  
25 rollers 523 constitute pressing means for pressing the rack shaft 510 toward the output shaft 503 from two directions.

In the present embodiment, a free end part 522b, which is the other end of the swingable shaft 522, is spherically shaped, and has contact with a truncated cone surface 521a as a pressing part of the main unit 521. In this regard, the swingable shaft 522 can be inserted and attached to the inside from an opening end (portion to which the screw member 524 is attached by screwing up) of the hollow columnar portion 501c. The main unit 521, the disc spring 525, and the screw member 524 constitute urging means.

In the present embodiment, the adjustments of the pressing forces  $F_1$ ,  $F_2$  (shown by reaction forces in Fig. 12) of the two cylindrical rollers 523 and the rolling contact surfaces (supporting unit guideway surfaces) 510b can be made by screwing up or screwing off the screw members 524 against the housing 501 to change an amount of the elastic deformation of the disc spring 525. In this case, the main unit 521 is moved rightward (substantially equal to the direction obtained by bisecting the angle formed by normal lines of the rolling contact surfaces 510b) in Fig. 12 based on the urging force of the disc spring 525, so that the truncated cone surfaces 521a press the free end parts 522b of the swingable shafts 522. Thereby, the two swingable shafts 522 swing about the center of the pin 528 in the opposite directions to each other, and thus it is possible to evenly

and appropriately adjust the pressing forces  $F_1$  and  $F_2$  between the two cylindrical rollers 523 and the rolling contact surfaces 510b. Also, even if a wear-out is caused at each part by, for example vibration, etc., the two swingable shafts 522 swing at the same time, and thus the pressing forces  $F_1$  and  $F_2$  do not grow unbalanced, and the rack shaft 510 can be supported stably for a long period of time. In this regard, the free end part 522b is spherically shaped and the tangent line between the truncated cone surface 521a and the free end part 522b is substantially parallel to the axis of the swingable shaft 522. Accordingly, even if the swingable shaft 522 swings, an unnecessary (that is to say, uncontributing to the pressing force of the cylindrical rollers 523) component force caused by that is small, and an edge load will not be exerted on the truncated cone surface 521a furthermore.

According to the present embodiment, the configuration of the supporting unit 520 can be made smaller to the same extent as the configuration in Figs. 1A, 1B and 2 as shown in Fig. 11. Also, the pressing force can be advantageously adjusted only by the screwing the single screw member 524. In the embodiment described above, the main unit 221, 521 constitutes a holding member.

25

Fig. 13 is a sectional view, similar to Fig. 2, of

an electric power steering apparatus according to a tenth embodiment. The present embodiment is different from the embodiment shown in Fig. 2 mainly in the configuration of the rack shaft characteristically. Thus, common components  
5 other than that are marked with the same numerals and symbols, and those descriptions are omitted. In this regard, in Fig. 13, a worm 22 formed on a rotational shaft 21 of a motor which is driven and controlled by an unillustrated controller has a meshing engagement with a worm wheel 23 attached in  
10 the upper vicinity of the output shaft 103. Assistive power of the motor is transmitted to the output shaft 103 through the worm 22 and the worm wheel 23.

Incidentally, in the embodiment in Fig. 2, although  
15 a pair of the cylindrical rollers 123, which are rolling members of the supporting unit 120, are rotationally supported by the needle bearings 122a with respect to the shafts 122 individually, the rollers are not restrained in the axial direction with respect to the shafts 122.  
20 Accordingly, when an axial direction load is input from the rack shaft 110 to the cylindrical rollers 123, the cylindrical rollers 123 might contact the main unit 121 of the supporting unit 120, and this might cause the problems described below.

25 In particular, as shown in Fig. 2, the rolling contact surfaces 110b, 110b of the rack shaft 110 for the cylindrical

rollers 123, 123 are disposed at a predetermined angle (90 degrees in the figure) to each other. The rotational shafts of the cylindrical rollers 123, 123 are perpendicularly to the axes of the rack shafts 110, respectively, and are parallel to the rolling contact surfaces 110b, 110b. Furthermore, the two cylindrical rollers 123, 123 are pressed on the rolling contact surfaces 110b, 110b by the screw member 124, which is an urging member, pressing in the bisector direction of the two rotational shafts.

10

That is to say, the pressing direction of the screw member 124 does not match the pressing direction of the cylindrical rollers 123, 123 against the rolling contact surfaces 110b, 110b. Thus, if the end surface of the cylindrical rollers 123, 123 contacts the screw member 124, a frictional force in the axial direction in accordance with the pressing force exerted on the rolling contact surfaces 110b, 110b arises depending on a frictional state between the cylindrical roller 123 and the rack shaft 110. Therefore, the end surfaces of the cylindrical rollers 123, 123 are strongly pressed against the main unit 121 by the axial direction frictional force to be frictionally slid. Accordingly, the smooth rotation of the cylindrical rollers 123, 123 is hindered, and the operational resistance of the rack shaft 110 becomes large. Also, the end surfaces of the cylindrical rollers 123, 123 might be worn out, and abnormal

noises might be produced.

Accordingly, in the embodiment shown in Fig. 13, a projection 610c of the rack shaft 610 is widened with respect to the embodiment in Figs. 1A and 1B, and a configuration is employed (arrow A) in which the root portions of both side surfaces 610d, 610d are used as position regulation parts to contact the end surfaces of the cylindrical rollers 123, 123. In this manner, the movement of the cylindrical rollers 123, 123 in the axial direction is regulated by the movement regulation parts (the root portions of the side surfaces 610d, 610d) disposed on the rack shaft 610, contacting the end surfaces of the cylindrical rollers 123, 123, in order to form a gap between the cylindrical rollers 123, 123 and the main unit 121, thereby preventing the frictional slide of the end surfaces of the rollers.

In this regard, the contact radius between the rolling contact surfaces 110b, 110b and the cylindrical rollers 123, 123 and the contact radius between the cylindrical rollers 123, 123 and the side surfaces 610d, 610d are a little different, and thus the cylindrical rollers 123, 123 and the movement regulation parts (the root portions of the side surfaces 610d, 610d) have a little difference in speed to cause slippage. However, it is possible to reduce a slip loss and to reduce slide resistance of the rack shaft 610 compared with the

case of slide contacting all the end surfaces of the rollers.

Fig. 14 is a sectional view, similar to Fig. 12, of an electric power steering apparatus according to an eleventh embodiment. The present embodiment is different from the embodiment shown in Fig. 12 mainly in the configuration of the rack shaft. Thus, common components other than that are marked with the same numerals and symbols, and those descriptions are omitted.

10

In the embodiment shown in Fig. 14, a projection 610c of the rack shaft 610 is widened with respect to the embodiment in Fig. 12, and a configuration is employed (arrow B) in which both side surfaces 610d, 610d are used as position regulation parts to contact the end surfaces of the cylindrical rollers 123, 123. In this manner, the movement of the cylindrical rollers 123, 123 in the axial direction is regulated by the movement regulation parts 610d, 610d disposed on the rack shaft 610, contacting the end surfaces of the cylindrical rollers 123, 123, in order to form a gap between the cylindrical rollers 123, 123 and the main unit 121, thereby preventing the frictional slide of the end surfaces of the rollers.

25

Fig. 15 is a sectional view, similar to Fig. 13, of an electric power steering apparatus according to a twelfth

embodiment. The present embodiment is different from the embodiment shown in Fig. 13 mainly in the configuration of the cylindrical rollers characteristically. Thus, common components other than that are marked with the same numerals and symbols, and those descriptions are omitted.

As described above, in the embodiment in Figs. 1A and 1B, the rolling contact surfaces 110b, 110b of the rack shaft 110 for the cylindrical rollers 123, 123 are disposed at a predetermined angle (90 degrees in the figure) to each other. The rotational shafts of the cylindrical rollers 123 are perpendicularly to the axes of the rack shafts 110, respectively, and are parallel to the rolling contact surfaces 110b, 110b. Furthermore, the two cylindrical rollers 123, 123 are pressed on the rolling contact surfaces 110b, 110b by the screw member 124, which is an urging member, pressing in the bisector direction of the two rotational shafts. That is to say, the pressing direction of the screw member 124 does not match the pressing direction of the cylindrical rollers 123, 123 against the rolling contact surfaces 110b, 110b.

A separation force which is caused by the meshing power transmission between the rack shaft 110 and the pinion 103a, and separates the rack shaft 110 from the pinion 103a is supported by the resultant force of the pressing forces acted

from the rollers 123 on the rolling contact surfaces 110b, 110b of the rack shaft 110. Thus, assuming that an angle formed by the acting direction of the pressing force of the cylindrical rollers 123, 123 and the separation force is  $\alpha$ , the load to be born by the needle bearings 122a becomes  
5 as large as  $1/\sin\alpha$  times the pressing force ( $\sqrt{2}$  times in the case where  $\alpha = 45$  degrees as in this embodiment).

Also, since the rotational shafts of the cylindrical  
10 rollers 123, 123 are inclined to the direction of the separation force, the main unit 121 of the supporting unit 120, which is inserted into an attachment opening disposed on the housing 101 and supports the cylindrical rollers 123, 123 must have a larger diameter than that of the circumscribed  
15 circle of the cylindrical rollers 123, 123. Therefore, in order to make the rack supporting part compact, the cylindrical rollers 123, 123 must be small in the axial direction and the radial direction. Thus, a large-sized and large-volume needle bearing 122a cannot be employed.  
20 However, if the configuration is not compact, it becomes difficult to mount the unit on a vehicle. Also, if the main unit 1 is large and heavy, the follow-up performance with respect to the rack shaft is deteriorated, and bumping noises between the rack shaft 110 and the pinion 103a or between  
25 the rack shaft 110 and the cylindrical rollers 123, 123 might occur.

Furthermore, the outer diameter of the cylindrical rollers 123, 123 must be set as small as possible. However, if the outer diameter of the cylindrical rollers 123, 123 are made smaller, the rotational speed of the cylindrical rollers 123, 123 increases. The load on the needle bearings 122a becomes large and the rotational lifetime of the bearings decreases, thereby the durability might be deteriorated.

In contrast, according to the embodiment shown in Fig. 15, the rack supporting part can be made compact, the follow-up performance can be improved by achieving easy mounting and light weight. Also, it is possible to improve the durability of the needle bearings.

More specifically, in the present embodiment, outward conical surfaces 723a, 723a are formed on the edge faces of the cylindrical rollers 723, 723 by cutting away the outer edges. The outer shapes (the distant side from the axis of the main unit 721) of the conical surfaces 723a, 723a is parallel to the outer circumference of the main unit 721 as viewed in cross section in Fig. 15. With this configuration, even if the outer diameter of the cylindrical rollers 723, 723 is made larger, it is possible to make the circumscribed circle of the cylindrical rollers 723, 723 small as viewed from the axial direction to the main unit

721. Accordingly, the total rotation number of the needle bearings 122a, 122a can be reduced, and thus the duration lifetime can be extended.

5            Fig. 16 is a sectional view, similar to Fig. 15, of an electric power steering apparatus according to a thirteenth embodiment. The present embodiment is different from the embodiment shown in Fig. 15 mainly in the configuration of the main unit of the supporting unit  
10           characteristically. Thus, common components other than that are marked with the same numerals and symbols, and those descriptions are omitted. The present embodiment has the same characteristic as that of the embodiment shown in Fig. 15, and thus it is possible to employ needle bearings 722a,  
15           722a having a large outer diameter and a large rated load volume. Thereby, it is possible to extend the duration lifetime of the needle bearings 122a, 122a furthermore.

             Here, a description will be given of the assembly steps  
20           of the supporting unit. In the embodiment in Figs. 1A, 1B, and 2, both ends of the shafts 122, 122 supporting the cylindrical rollers 123, 123 are supported by the main unit 121. Thus, in order to ensure the shaft supporting parts of the peripheral side of the main unit 121 without making  
25           the main unit 121 larger, it is necessary for to assemble the roller accommodation part of the main unit 121 from the

direction perpendicular to the shafts 122, 122.

A more specific description will be given. First, on the main unit 121 as a single item, a roller accommodation part 121g and an axial hollow 121h are formed by one set  
5 by forging and machine work, respectively (Fig. 17A). A view of this main unit 121 as viewed in the direction of the arrow XVIII in Fig. 17A is Fig. 18. One of the cylindrical rollers 123 to which the needle bearing 122a has been assembled is  
10 accommodated into one of the roller accommodation parts 121g of the main unit 121 in this state, and is fitted so as to be pierced by the shaft 122 inserted into the axial hollow 121h (Fig. 17B). Furthermore, the other of the cylindrical rollers 123 to which the needle bearing 122a has been assembled  
15 is accommodated into the other of the roller accommodation parts 121g, and is fitted so as to be pierced by the shaft 122 inserted into the axial hollow 121h (Fig. 17C). The assembly of the main unit 121 is completed in this manner (Fig. 17D). However, as is apparent from Fig. 18, the main  
20 unit 121 requires complicated machine work, has unnecessary thickness and considerable weight, and the manufacturing cost is high.

In contrast, in the embodiment in Figs. 15 and 16,  
25 it is possible to assemble the rollers from the axial direction of the main unit 721 by providing conical surfaces 723a,

723a on the cylindrical rollers 723, 723 in an assembled state.

A more specific description will be given. First, on  
5 the main unit 721 as a single item, a roller accommodation  
part 721g and an axis containing part 721h are formed by  
one set (Fig. 19A). A view of this main unit 721 as viewed  
in the direction of the arrow XX in Fig. 19A is Fig. 20.  
A view of the main unit in Fig. 19A as viewed in the direction  
10 of the arrow XXI is Fig. 21. A view of the main unit in Fig.  
19A as viewed in the direction of the arrow XXII is Fig.  
22. A view of the main unit in Fig. 22, cut off by the line  
XXIII-XXIII as viewed in the arrow direction is Fig. 23.

15 Two pieces of the cylindrical rollers 723 to which  
the shaft 122 and the needle bearing 122a have been assembled  
are accommodated into the roller accommodation parts 121g  
and the axis containing part 721h of the main unit 721 in  
this state in parallel (may be separately), and thus the  
20 assembly of the main unit 721 is completed (Fig. 19C).  
Accordingly, it is possible for the main unit 721 (at least  
a part for supporting the rolling members) to have a shape  
capable of being molded in the axial direction. Therefore,  
it becomes possible to manufacture the unit by a molding  
25 process such as cold forging, sintering, metal-injection  
molding, resin-injection molding, etc. Thus, it is possible

to eliminate unnecessary thickness to achieve weight reduction and to reduce cost significantly. In this regard, if a thinning part 721s is provided on the back surface of the main unit 121, it is possible to further reduce the weight of the main unit 1.

The present invention has been explained in depth so far with reference to the embodiments. The present invention should not, however, be construed as limited to the embodiments described above and can be, as a matter of course, modified and improved properly within the range that does not spoil the gist of the invention. For example, the pressing direction of the pressing part may be three directions or more. Also, the present invention is not limited only to a variable stroke-ratio-type electric power steering apparatus. The present invention is also suitable for a constant stroke-ratio-type electric power steering apparatus, a column-assist type, a pinion-assist type, or a rack-assist type electric power steering apparatus.